



Clinical value of pulse wave velocity: a promising marker for arterial stiffness

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Pulse wave velocity (PWV) has emerged as a marker for arterial stiffness with a promising future role in cardiovascular risk stratification. The pressure wave produced by systolic pumping of the heart travels along the aorta and other vasculature throughout the body. With deterioration of the vessel wall, whether due to age, connective tissue disease or atherosclerosis, the transit time of the pulse wave from point A to B becomes shorter, meaning that PWV is directly related to the mechanical properties of the vessel. Cardiovascular disease leading to aortic dilatation typically occurs through a gradual process, although the clinical manifestation can be acute. Feared complications of aortic dilatation are dissection and rupture, with a high risk for mortality and morbidity. Indication for preventive surgical intervention is currently mostly based on aortic diameter. An added measure for detection of subclinical aortic disease is desirable for more tailored risk stratification to guide preventive intervention.

Several methods are available for measuring PWV, all based on the general principle $PWV = \Delta d / \Delta t$ where Δd is the distance between two planes and Δt is the temporal shift between two waveforms. Intravascular pressure or flow-derived PWV is the gold standard method, but unattractive for general implementation due to its invasive nature. Non-invasive methods include vascular applanation tonometry or Doppler ultrasound over the carotid and femoral artery (i.e. external measurement of pressure or flow velocity respectively). Their main pitfall is inaccuracy due to erroneous distance measurement, especially in obese patients. A more

recent non-invasive approach to measure PWV is by using cardiovascular magnetic resonance imaging (CMR). CMR-derived PWV is more reliable, not limited by imaging planes, and CMR offers more possibilities regarding cardiovascular imaging (i.e. aortic anatomy, plaque visualisation and characterisation, cardiac function, carotid patency). Specifically regarding PWV, CMR also allows measurement of regional PWV in addition to global PWV, which will be discussed later. Moreover, CMR is increasingly implemented in routine clinical care and becoming more widely available.

Through-plane velocity-encoded CMR at two (or more) sites perpendicular to the aorta is the most commonly used CMR technique for PWV assessment. The accuracy and reliability of CMR-based PWV assessment depends on temporal resolution, spatial sampling density and accurate ECG gating. There are several post-processing methods, but currently the time-to-foot method is used most often. After reconstruction of the waveform at each acquisition plane, the temporal shift (or transit time) between the waveforms is assessed using the foot of the waveforms: the intersection of a line fitted to the waveform upslope (through data points at 20 and 80 % of maximum velocity) with the horizontal axis or base velocity. Alternatively, the cross-correlation method has been suggested [1]; however, there is no consensus yet regarding a method of preference.

In 2010, Westenberg et al. [2] validated two-directional in-plane velocity-encoded CMR and showed better correlation with the gold standard and better reproducibility than 'traditional' through-plane velocity-encoded CMR. With this technique flow velocity is assessed lengthwise in the aorta (from the candy cane view) as opposed to cross-sectionally in the through-plane method. From the acquired images cross-sectional planes along the aortic centreline are defined, producing 200 waveforms from which PWV can be derived. By segmenting the aorta in a standardised fash-

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ion, regional PWV values can be determined. Local PWV assessment is possible as well, but accuracy depends on the temporal resolution. The in-plane CMR technique is more time consuming due to increased scanning time and more intensive image processing, but its unique strength lies in the ability to determine regional and local PWV. Theoretically, regional aortic stiffness assessment might allow early detection of disease, whereas global PWV can still be normal if the aorta is only affected regionally.

The predictive value of PWV has been assessed in a sub-study of the Dallas Heart Study in 2122 healthy subjects with an 8-year follow-up period [3]. The study showed CMR-derived PWV to be associated with the occurrence of cardiovascular events and improved risk stratification when added to the Framingham Risk Score. In the general population PWV seems potentially useful in trials regarding atherosclerosis, however, it may have more clinical potential in patients at risk for progression of aortic disease. In 2013 Kröner et al. [4] investigated regional PWV as a predictor for aortic dilatation over time in patients with Marfan syndrome using the in-plane velocity-encoded MR technique. They confirmed previous data by showing higher PWV in Marfan patients compared with healthy control subjects, and a moderate to high specificity for regional PWV as a predictor for aortic diameter growth. In the current issue of the NHJ, Kröner et al. [5] studied the relation of regional PWV and aortic diameter in patients with thoracic aortic aneurysm, using in-plane velocity-encoded CMR, and show promising results. They demonstrated high specificity in the descending thoracic and abdominal aorta and moderate specificity for the ascending aorta and aortic arch. On the other hand, sensitivity was surprisingly low. The results of the study are mostly driven by the small number of patients and low prevalence of the outcome measure (i.e. abnormal diameter). Regardless, normal PWV seems to successfully identify absence of disease, which in itself is also useful. It is unknown how PWV performs in patient groups with more extensive disease, and additionally how PWV will eventually monitor patients with aortic disease and indicate timing of surgical intervention.

Concluding, PWV as assessed by CMR is reliable, feasible and has high potential as an arterial stiffness marker. Small studies in patients at risk for (further) aortic dilatation show normal PWV to indicate absence of increased aortic diameter, which might improve cardiovascular risk stratification. Clinical implementation will depend on the predictive value of PWV in further studies with specific at-risk patient populations, larger cohorts, longer follow-up and monitoring of clinical events. Ideally, if PWV improves our current risk stratification, high-risk patients can be referred for surgical intervention timely, and low-risk patients can be deferred safely.

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